

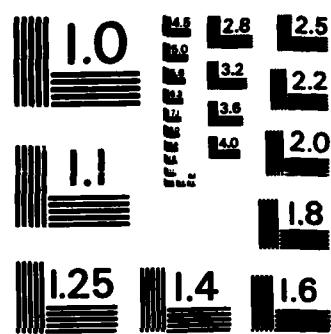
AD-A160 325 ANALYSIS OF PREPROCESSORS AND DECISION AIDS IN
ORGANIZATIONS(U) MASSACHUSETTS INST OF TECH CAMBRIDGE
LAB FOR INFORMATION AND D. G H CHYEN ET AL. FEB 85
UNCLASSIFIED LIDS-P-1438 AFOSR-TR-85-0819 AFOSR-88-0229 F/G 5/1

1/1

NL



END
IN MED
OTK



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE

AD-A160 325

REPORT DOCUMENTATION PAGE

1a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED		1b. RESTRICTIVE MARKINGS <i>(Signature)</i>												
1c. SECURITY CLASSIFICATION AUTHORITY		3d. DISTRIBUTION/AVAILABILITY OF REPORT Approved for public release; distribution unlimited.												
2. DECLASSIFICATION/DOWNGRADING SCHEDULE														
3. PERFORMING ORGANIZATION REPORT NUMBER(S) LIDS-P-1438		5. MONITORING ORGANIZATION REPORT NUMBER(S) AFOSR-TR- 85-0819												
6a. NAME OF PERFORMING ORGANIZATION Massachusetts Institute of Technology	6b. OFFICE SYMBOL (If applicable)	7a. NAME OF MONITORING ORGANIZATION Air Force Office of Scientific Research												
7b. ADDRESS (City, State and ZIP Code) Laboratory for Information and Decision Systems, Cambridge MA 02139		7b. ADDRESS (City, State and ZIP Code) Directorate of Mathematical & Information Sciences, Bolling AFB DC 20332-6448												
8a. NAME OF FUNDING/SPONSORING ORGANIZATION AFOSR	8b. OFFICE SYMBOL (If applicable) NM	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER AFOSR-80-0229												
10c. ADDRESS (City, State and ZIP Code) Bolling AFB DC 20332-6448		10. SOURCE OF FUNDING NOS. <table border="1"> <tr> <td>PROGRAM ELEMENT NO. 61102F</td> <td>PROJECT NO. 2304</td> <td>TASK NO. A1</td> <td>WORK UNIT NO.</td> </tr> </table>		PROGRAM ELEMENT NO. 61102F	PROJECT NO. 2304	TASK NO. A1	WORK UNIT NO.							
PROGRAM ELEMENT NO. 61102F	PROJECT NO. 2304	TASK NO. A1	WORK UNIT NO.											
11. TITLE (Include Security Classification) ANALYSIS OF PREPROCESSORS AND DECISION AIDS IN ORGANIZATIONS														
12. PERSONAL AUTHOR(S) Gloria H.-L. Chyen, Alexander H. Levis														
13a. TYPE OF REPORT Technical	13b. TIME COVERED FROM _____ TO _____	14. DATE OF REPORT (Yr., Mo., Day) FEB 85	15. PAGE COUNT 7											
16. SUPPLEMENTARY NOTATION														
17. COSATI CODES <table border="1"> <tr> <th>FIELD</th> <th>GROUP</th> <th>SUB. GR.</th> </tr> <tr> <td> </td> <td> </td> <td> </td> </tr> <tr> <td> </td> <td> </td> <td> </td> </tr> <tr> <td> </td> <td> </td> <td> </td> </tr> </table>	FIELD	GROUP	SUB. GR.										18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)	
FIELD	GROUP	SUB. GR.												
19. ABSTRACT (Continue on reverse if necessary and identify by block number) The use of preprocessors and decision aids in command, control and communication (C3) systems is meant to reduce the workload of individual decisionmakers and improve the quality of an organization's decisionmaking. An information theoretic framework is used to model the decision aids. Thus, it becomes possible to evaluate quantitatively the effect a decision aid has on the workload of a decisionmaker and to derive necessary conditions that preprocessors (a generic form of decision aids) must satisfy in order that they reduce the human's workload.				20. DISTRIBUTION/AVAILABILITY OF ABSTRACT UNCLASSIFIED/UNLIMITED <input checked="" type="checkbox"/> SAME AS RPT. <input type="checkbox"/> DTIC USERS <input type="checkbox"/>										
21. ABSTRACT SECURITY CLASSIFICATION UNCLASSIFIED				22. TELEPHONE NUMBER (Include Area Code) (202) 767-4940										
22a. NAME OF RESPONSIBLE INDIVIDUAL Dr. Marc Q. Jacobs				22c. OFFICE SYMBOL NM										

DD FORM 1473, 83 APR

EDITION OF 1 JAN 73 IS OBSOLETE.

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE

MSF

DTIC
SELECT

OCT 15 1985

FEBRUARY 1985

LIDS-P-1438

ANALYSIS OF PREPROCESSORS AND DECISION AIDS IN ORGANIZATIONS*



by

Gloria H.-L. Chyen

Alexander H. Levis

Laboratory for Information and Decision Systems

Massachusetts Institute of Technology, Cambridge, MA 02139 USA

1	2	3	4
5	6	7	8
9	10	11	12
13	14	15	16
17	18	19	20
21	22	23	24
25	26	27	28
29	30	31	32
33	34	35	36
37	38	39	40
41	42	43	44
45	46	47	48
49	50	51	52
53	54	55	56
57	58	59	60
61	62	63	64
65	66	67	68
69	70	71	72
73	74	75	76
77	78	79	80
81	82	83	84
85	86	87	88
89	90	91	92
93	94	95	96
97	98	99	100
101	102	103	104
105	106	107	108
109	110	111	112
113	114	115	116
117	118	119	120
121	122	123	124
125	126	127	128
129	130	131	132
133	134	135	136
137	138	139	140
141	142	143	144
145	146	147	148
149	150	151	152
153	154	155	156
157	158	159	160
161	162	163	164
165	166	167	168
169	170	171	172
173	174	175	176
177	178	179	180
181	182	183	184
185	186	187	188
189	190	191	192
193	194	195	196
197	198	199	200
201	202	203	204
205	206	207	208
209	210	211	212
213	214	215	216
217	218	219	220
221	222	223	224
225	226	227	228
229	230	231	232
233	234	235	236
237	238	239	240
241	242	243	244
245	246	247	248
249	250	251	252
253	254	255	256
257	258	259	260
261	262	263	264
265	266	267	268
269	270	271	272
273	274	275	276
277	278	279	280
281	282	283	284
285	286	287	288
289	290	291	292
293	294	295	296
297	298	299	300
301	302	303	304
305	306	307	308
309	310	311	312
313	314	315	316
317	318	319	320
321	322	323	324
325	326	327	328
329	330	331	332
333	334	335	336
337	338	339	340
341	342	343	344
345	346	347	348
349	350	351	352
353	354	355	356
357	358	359	360
361	362	363	364
365	366	367	368
369	370	371	372
373	374	375	376
377	378	379	380
381	382	383	384
385	386	387	388
389	390	391	392
393	394	395	396
397	398	399	400
401	402	403	404
405	406	407	408
409	410	411	412
413	414	415	416
417	418	419	420
421	422	423	424
425	426	427	428
429	430	431	432
433	434	435	436
437	438	439	440
441	442	443	444
445	446	447	448
449	450	451	452
453	454	455	456
457	458	459	460
461	462	463	464
465	466	467	468
469	470	471	472
473	474	475	476
477	478	479	480
481	482	483	484
485	486	487	488
489	490	491	492
493	494	495	496
497	498	499	500
501	502	503	504
505	506	507	508
509	510	511	512
513	514	515	516
517	518	519	520
521	522	523	524
525	526	527	528
529	530	531	532
533	534	535	536
537	538	539	540
541	542	543	544
545	546	547	548
549	550	551	552
553	554	555	556
557	558	559	560
561	562	563	564
565	566	567	568
569	570	571	572
573	574	575	576
577	578	579	580
581	582	583	584
585	586	587	588
589	590	591	592
593	594	595	596
597	598	599	600
601	602	603	604
605	606	607	608
609	610	611	612
613	614	615	616
617	618	619	620
621	622	623	624
625	626	627	628
629	630	631	632
633	634	635	636
637	638	639	640
641	642	643	644
645	646	647	648
649	650	651	652
653	654	655	656
657	658	659	660
661	662	663	664
665	666	667	668
669	670	671	672
673	674	675	676
677	678	679	680
681	682	683	684
685	686	687	688
689	690	691	692
693	694	695	696
697	698	699	700
701	702	703	704
705	706	707	708
709	710	711	712
713	714	715	716
717	718	719	720
721	722	723	724
725	726	727	728
729	730	731	732
733	734	735	736
737	738	739	740
741	742	743	744
745	746	747	748
749	750	751	752
753	754	755	756
757	758	759	760
761	762	763	764
765	766	767	768
769	770	771	772
773	774	775	776
777	778	779	780
781	782	783	784
785	786	787	788
789	790	791	792
793	794	795	796
797	798	799	800
801	802	803	804
805	806	807	808
809	810	811	812
813	814	815	816
817	818	819	820
821	822	823	824
825	826	827	828
829	830	831	832
833	834	835	836
837	838	839	840
841	842	843	844
845	846	847	848
849	850	851	852
853	854	855	856
857	858	859	860
861	862	863	864
865	866	867	868
869	870	871	872
873	874	875	876
877	878	879	880
881	882	883	884
885	886	887	888
889	890	891	892
893	894	895	896
897	898	899	900

*This work was supported by the U. S. Air Force Office of Scientific Research under Contract AFOSR-80-0229.

Approved for public release;
distribution unlimited.

85 10 11 090

ANALYSIS OF PREPROCESSORS AND DECISION AIDS IN ORGANIZATIONS*

Gloria H.-L. Chyen
Alexander H. Lewis
Laboratory for Information and Decision Systems
Massachusetts Institute of Technology, Cambridge, MA 02139 USA

Abstract: The use of preprocessors and decision aids in command, control and communication ('C') systems is meant to reduce the workload of individual decisionmakers and improve the quality of an organization's decisionmaking. An information theoretic framework is used to model the decision aids. Thus, it becomes possible to evaluate quantitatively the effect a decision aid has on the workload of a decisionmaker and to derive necessary conditions that preprocessors (a generic form of decision aids) must satisfy in order that they reduce the human's workload.

Keywords: Decision Aids, Organization Theory

INTRODUCTION

The objective of the research presented in this paper is twofold: (a) to extend a mathematical theory of organizations to include decision aids and (b) to provide an interpretation of some recent experimental results on multiple tasking of decisionmakers. The unifying concept is that of a preprocessor - a processor located between the data source (or stimulus) and the situation assessment stage of a decisionmaker. A simple decision aid can be modeled by an external preprocessor while for interpreting the experimental results an internal preprocessor is introduced.

One function of decision aids is to reduce a decisionmaker's workload. One way of doing that is by pre-processing the incoming data. Another mechanism is to reduce the input rate by filtering out irrelevant data. This saves processing resources and increases the time available to process individual inputs. The decisionmaker need attend only to the significant data and therefore, the system performance is enhanced.

The model of the human decisionmaker used in this paper is the descriptive one presented in Boettcher and Lewis (1983, 1984) and Lewis and Boettcher (1983). The model of the preprocessor is linked to the decisionmaker model so that its ability to reduce the processing workload of the decisionmaker can be analyzed.

The basic information theoretic model of the decisionmaker is a two-stage process with limited processing capacity; it is illustrated in Fig. 1. The decisionmaker receives an input symbol x from his environment. If the input symbols are generated every τ seconds on the average, then τ , the mean symbol interarrival time, is a description of the tempo of operations. The situation assessment (SA) stage consists of a finite number of well-defined deterministic or stochastic algorithms that the decisionmaker can choose from to process the measurement x and obtain the assessed situation z . The internal decision u in this stage is the choice of algorithm f_i to process x . Therefore, each algorithm is considered to be

active or inactive, depending on the internal decision strategy $p(u)$. In the response selection (RS) stage, which is similar to the situation assessment stage, one of the algorithms h_j is chosen according to the response selection strategy $p(v|z)$ to process the situation assessment z into an appropriate response y . Since no learning takes place during the performance of a sequence of tasks, the successive values taken by the variables of the model are uncorrelated, i.e., the model is memoryless. Hence, all information theoretic expressions in this paper are on a per symbol basis.

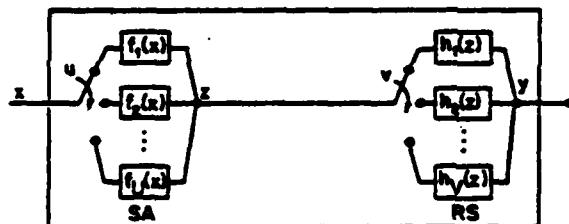


Figure 1. Basic Model of Decisionmaking Process

The model of the decisionmaking process shown in Fig. 1 may be viewed as a system S consisting of two subsystems, S^A and S^R , that correspond to each one of the two stages. The input to this system S is x and the output is y . Furthermore, let each algorithm f_i contain a_i variables denoted by

$$v^i = \{v_1^i, v_2^i, \dots, v_{a_i}^i\} \quad i = 1, 2, \dots, u \quad (1)$$

and let each algorithm h_j contain a_j variables denoted by

$$w^{j+1} = \{w_1^{j+1}, w_2^{j+1}, \dots, w_{a_j}^{j+1}\} \quad j = 1, 2, \dots, v \quad (2)$$

It is assumed that the algorithms have no variables in common:

$$v^i \cap w^j = \emptyset \quad \text{for } i \neq j \quad i, j = 1, 2, \dots, u, v \quad (3)$$

The subsystem S^A is described by a set of variables

Approved for public release;
distribution unlimited.

*This work was supported by the U.S. Air Force Office of Scientific Research under Contract AFOSR-80-0229.

$$S^{SA} = (u, v^1, \dots, v^U, z) \quad (4)$$

and subsystem S^{RS} by

$$S^{RS} = (v, v^{U+1}, \dots, v^{U+V}, y) \quad (5)$$

The four quantities stated in the Partition Law of Information (Conant, 1976) for this system S can be evaluated with the following results.

Throughput:

$$G_t = T(x:y) = H(y) - H_x(y) \quad (6)$$

Blockage:

$$G_b = T(x:u, v^1, \dots, v^{U+V}, z, v) = H(x) - G_t \quad (7)$$

In this case, inputs not received or rejected by the system are not taken into account.

Noise:

$$G_n = H_x(S^{SA}, S^{RS}) = H(u) + H_v(v) \quad (8)$$

Coordination:

$$G_c = T(u:v^1: \dots :v^{U+V}:z:v:y) = G_c^{SA} + G_c^{RS} + T(S^{SA}:S^{RS}) \quad (9)$$

where

$$G_c^{SA} = \sum_{i=1}^U [p_i g_c^{U+i}(p(x)) + a_i H(p_i)] + H(z) \quad (10)$$

$$G_c^{RS} = \sum_{j=1}^V [p_j g_c^{U+j}(p(z|v=j)) + a_j H(p_j)] + H(y) \quad (11)$$

$$T(S^{SA} : S^{RS}) = H(z) \quad (12)$$

The quantity $H(x)$ denotes the entropy of the random variable x and $H_x(y)$ is the conditional entropy of y when x is given. The expression for G_n shows that it depends on both internal strategies $p(u)$ and $p(v|z)$. In the subsystem coordination expressions G_c^{SA} and G_c^{RS} , p_i and p_j are, respectively the probabilities that algorithms i and j have been selected, i.e., $p_i = p(u=i)$ and $p_j = p(v=j)$. The quantities g_c^{U+i} represent the internal coordination of the corresponding algorithms and depend on the probability distributions of their respective inputs. The quantity H is the entropy of a Bernoulli random variable with parameter p :

$$H(p) = -p \log p - (1-p) \log (1-p) \quad (13)$$

Eq. (9) states that the total coordination in the system S can be expressed as the sum of the internal coordination within each subsystem given by Eqs. (10) and (11) and the coordination due to the interaction between the two subsystems given by Eq. (12).

The subsystem coordination consists of terms reflecting the presence of switching due to the

internal decision strategies $p(u)$ or $p(v|z)$. If there is no switching, i.e., if, for example $p(u=i)=1$ for some i , then H will be identically zero and Eq. (10) will reduce to:

$$G_c^{SA} = g_c^1(p(x)) + H(z) \quad (14)$$

Finally, the total information processing activity of the system G is given by

$$G = G_t + G_b + G_n + G_c \quad (15)$$

it can serve as a measure of the workload of the decisionmaker in carrying out this task. (Boettcher and Lewis, 1982)

The paper has been organized as follows. In the next section, the basic model of preprocessors and decision aids is introduced. The preprocessor model is connected to the decisionmaker model for system evaluation. A numerical example is provided to illustrate the utility of a preprocessor in a decisionmaking system. Also, guidelines for the role of preprocessors in decisionmaking systems are developed. In the final section the question of how a preprocessor can facilitate dual-task processing by a decisionmaker is investigated by formulating two versions of a dual-task problem and analyzing one of them.

THE PREPROCESSOR MODEL

A preprocessor (PP) is located between a source and a decisionmaker (DM). In the simplest case considered here the PP operates on the decisionmaker's input variable only; hence, the PP consists of a single algorithm for preliminary processing of the input. It yields a SA decision strategy, $p(u|x)$, and sometimes a modified input x to the DM. Consequently, if the function of a PP is specified, i.e., the algorithm and the interconnections of the internal variables, the activity within the PP is computable, just like for the other algorithms within the SA and RS stages of the DM model.

A simple example of a PP illustrates how the various activity terms can be computed for a specified algorithm with well-defined internal variables. The function of the preprocessor in this example is to reduce the workload of the decisionmaker by processing some of the data before they are received by the DM. In order to evaluate the utility of the PP, two different decisionmaking systems, shown in Figs. 2 and 3, are considered.

The first one represents an unaided DM while the second one represents a DM with a preprocessor. The DMs in both systems is identical structures and algorithms. The PP in the second system is an algorithm that performs the same function as the SA stage of the first DM system. Since the PP is just an algorithm without any decisionmaking capability, the SA stage of the first DM system has to employ a pure strategy, i.e., the same algorithm is always selected to process the arriving inputs. Under such conditions, the decisionmaking process in both systems are identical. In order to allow the two systems to do the same task with the same performance, so that the activity or workload can be compared properly, the algorithms within the processes are assumed to be deterministic and their output distributions $p(y)$ identical. The latter result will be ensured, if the RS stage in the DM of both systems has the same input distribution $p(z)$ and decision strategy $p(v|z)$. Since the second system has executed the SA job within its preprocessor, its SA stage simply transmits its input to an identity algorithm so that the

distribution $p(z)$ within both systems will be identical.

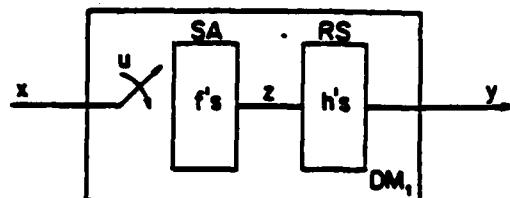


Figure 2. Basic DM System

With such a processing setup, the two systems carry out the same task with the same performance. To demonstrate the utility of the PP in the second system, the total activity within each system has to be evaluated.

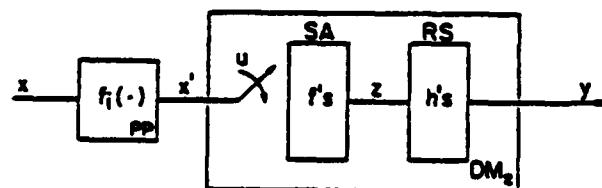


Figure 3. Aided DM System

Let:

$$G_{DM_1} = \text{Activity within First System} \quad (16a)$$

$$G_{DM_2} + G_{PP} = \text{Activity within Second System} \quad (16b)$$

where G_i is the total activity with subsystem i .

The expression for the total activity of a decisionmaker is given by:

$$G_{DM} = H(x) + H(u) + \sum_{i=1}^U p_i s_i^1 + \sum_{i=1}^U a_i H(p_i) + H(z) + H_z(v) \\ + \sum_{j=1}^V p_j s_a^{U+j} (p(z|v=j)) + \sum_{j=1}^V a'_j H(p_j) + H(y) + H(z) \quad (17)$$

Since the response selection process, input distribution $p(z)$ and decision strategy $p(v|z)$ of the RS stage in both systems are assumed identical, the activity within the RS stage of the two systems is the same, denoted by G_{RS} .

$$G_{RS} = H_z(v) + \sum_{j=1}^V p_j s_a^{U+j} (p(z|v=j)) + \sum_{j=1}^V a'_j H(p_j) \\ + H(y) + H(z) \quad (18)$$

Assume that the pure strategy in the SA stage of

the first system is such that the i^{th} algorithm is always selected (i.e., $p(i)=1$) whereas in the second system the first algorithm, which is an identity algorithm, is always selected. Then the activity of each decisionmaker in the two systems is obtained from the expressions in Eqs. (17) and (18)

$$G_{DM_1} = H(x) + s_a^1 + H(z) + G_{RS} \quad (19a)$$

$$G_{DM_2} = H(x') + s_a^1 + H(z) + G_{RS} \quad (19b)$$

The preprocessor in the second system consists of a single algorithm without any decisionmaking capability. The algorithm in this case is identical to the i^{th} algorithm of the SA stage, hence the activity within the PP is simply

$$G_{PP} = H(x) + s_a^1 \quad (20)$$

The function of the identity algorithm $s_a^1(\cdot)$ is to transmit its input to its output without any internal processing. Therefore, there is only one output variable z which duplicates the input value x and there are no internal variables. Its internal coordination is then

$$s_a^1 = T(\phi:z) = 0 \quad (21)$$

Since the internal coordination of any nontrivial algorithm (i.e., other than the identity algorithm) is greater than zero, $s_a^1 > 0$, it follows that

$$s_a^1 > s_a^1 \quad (22)$$

Given that the PP contains a deterministic algorithm without any decisionmaking capability, then

$$H(x) \geq H(x') > 0. \quad (23)$$

According to Eqs. (19a) to (23), the following two inequalities will always be valid.

$$G_{DM_1} > G_{DM_2} \quad (24)$$

$$G_{DM_1} < G_{DM_2} + G_{PP} \quad (25)$$

From the expressions of the total activity within the two DM systems given in Eqs. (15) and (16), the inequalities in Eqs. (24) and (25) show that even though the workload of the first system is less than that of the second system, the presence of the PP makes the workload of the second decisionmaker to be less than that of the first one. This result establishes a preprocessor's ability to reduce the activity of a decisionmaker. Therefore, decision aids that perform part of the situation assessment, e.g., some of the signal processing, are indeed useful devices, because they reduce some of the decisionmaker's processing load.

THE DUAL-TASK PROBLEM

Another application of the preprocessor is to facilitate a decisionmaker in handling two

concurrent tasks. When the measure of performance is properly defined the system performance of the dual-task case can be compared with that of single-task case.

Two variants of the dual-task problem have been investigated (Chyen, 1984). One is the sequential dual-task problem in which inputs of two different tasks arrive one after another in a sequential manner. The other is the parallel dual-task problem in which inputs of the two tasks arrive in parallel in a synchronous manner. For the single-task case, the input arrival rate will be identical to the rate of the dual-task case in order to compare properly the two workloads.

In this section, the sequential dual-task problem in the context of a single decisionmaker aided by a preprocessor will be formulated and then analyzed to determine the effect that executing two non-synergistic tasks can have on system performance.

The model of the sequential dual-task processing shown in Fig. 4 consists of a preprocessor and a decisionmaker.

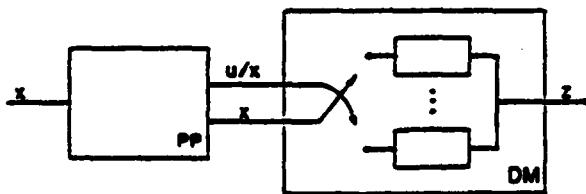


Figure 4. Sequential Dual-Task Processing Model

The input x of the system may be from task A with input alphabet X_A , or task B with input alphabet X_B . The PP examines each individual input to distinguish the task to which the particular input belongs. If it is a task A input, then the PP will yield a decision strategy $p(u_A)$ pertaining to task A to the DM for processing the input; otherwise strategy $p(u_B)$ pertaining to task B will be generated.

These decision strategies are the variables determining system activity and system performance. A pure or deterministic strategy means that a specific algorithm is always chosen to process the inputs from that particular task. A mixed or stochastic strategy is one obtained as a convex combination of pure strategies. In order to simplify the analysis that follows, it is assumed that there are only two pure strategies available for each individual task. When the four pure strategies of the two tasks are denoted by $u_A^1, u_A^2, u_B^1, u_B^2$, the mixed strategies u_A and u_B of the two tasks can be written as functions of decision strategy parameters δ_A or δ_B which correspond to the probabilities of employing pure strategies u_A^1 and u_B^1 respectively.

$$u_j = \delta_j u_j^1 + (1-\delta_j) u_j^2 \quad 0 \leq \delta_j \leq 1 \quad j=A, B \quad (26)$$

Again, for the sake of simplicity, only the decision strategies of the SA stage are considered. The situation assessment variable z is the system output.

Given that z' is the desired decision response, the performance J of a decisionmaking task can be defined as the probability of error in determining z . Since two tasks are being performed, their measures of performance J_A and J_B are defined as the probabilities of error in executing task A and task B respectively.

$$J_j = p(z \neq z') | z \in X_j \quad j = A, B \quad (27)$$

If the performance measure, evaluated when a pure strategy is in effect, is denoted by J_A^1 and J_B^1 , respectively, then the quantities J_A and J_B can be rewritten as functions of the parameters δ_A and δ_B that specify the decision strategies u_A and u_B :

$$J_j(\delta_j) = \delta_j J_j^1 + (1-\delta_j) J_j^2 \quad j = A, B \quad (28)$$

Now the measure of overall performance for the system can be defined by the probability of making a task A error or a task B error. If ϵ is the probability of the system processing task A inputs, then by assuming errors on both tasks to be equally detrimental the system performance J can be written as

$$J(\epsilon) = \epsilon J_A(\delta_A) + (1-\epsilon) J_B(\delta_B) \quad 0 \leq \epsilon \leq 1 \quad (29)$$

Graphically, for a fixed ϵ , the system performance J can be plotted as a tilted plane with boundaries at the planes $\delta_A=0$ and 1 and $\delta_B=0$ and 1. The plane in the 3-dimensional space (J, δ_A, δ_B) is shown in Fig. 5.

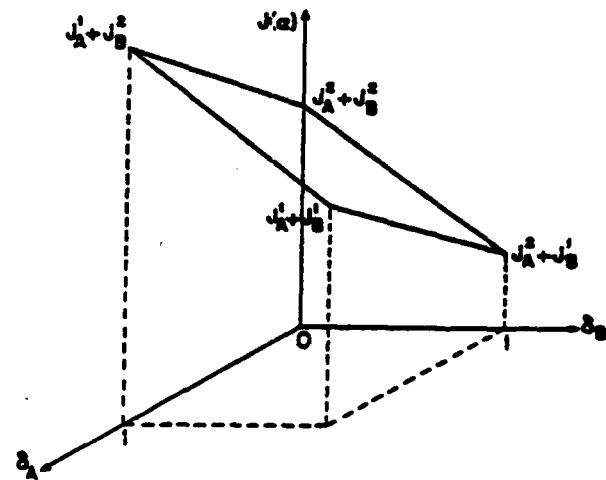


Figure 5. Total Performance Versus Decision Strategy Parameters δ_A and δ_B

The total activity of the system for single-task processing is a convex function of the decision strategy parameters δ_A and δ_B , whereas that of dual-task processing is a convex function of the task division parameter ϵ as well as the decision strategy parameters δ_A and δ_B . The convexity of the system activity G in ϵ as well as in δ_A and δ_B has been demonstrated by Hall (1982).

$$G_j(\delta_j) \geq \delta_j G_j^1 + (1-\delta_j) G_j^2 \quad j = A, B \quad (30)$$

$$G(\epsilon) \geq \epsilon G_A(\delta_A) + (1-\epsilon) G_B(\delta_B) \quad (31)$$

A typical graph of G for a fixed ϵ is shown in Fig. 6.

The system activity or workload in Fig. 6 is a curved bounded surface with four corners (somewhat like a tent). When, for a fixed ϵ , J is plotted against G , parametrically with respect to (δ_A, δ_B) the performance-workload locus for the whole system can be constructed.

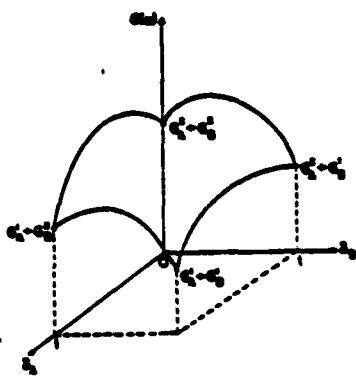


Figure 6. Total Workload Versus Decision Strategy Parameters δ_A and δ_B

To simplify the construction of the locus, but without any loss of generality, it is assumed that $\delta_A = \delta_B = \delta$, i.e., both task A and task B employ the same rule in decisionmaking (but the content of the decisions may be different). For example, if there are four algorithms f_1, f_2, f_3 , and f_4 , in the DM, the pure strategies of the two tasks can be defined as employing different algorithms. For instance, for task A: u_A^1 means $u=1$; u_A^2 means $u=2$; while for task B: u_B^1 means $u=3$ and u_B^2 means $u=4$. Then the mixed strategies, u_A and u_B , will have the same form but different content in the decisionmaking process.

$$u_j = \delta u_j^1 + (1-\delta)u_j^2 \quad j = A, B \quad (32)$$

With such a formulation, Fig. 6 will degenerate into the 2-dimensional plot shown in Fig. 7.

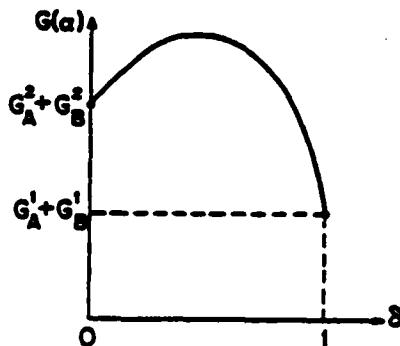


Figure 7. Workload Versus Decision Strategy Parameter δ

Therefore, the J-G plot of the system for a fixed ϵ can be drawn parametrically with respect to δ (Fig. 8).

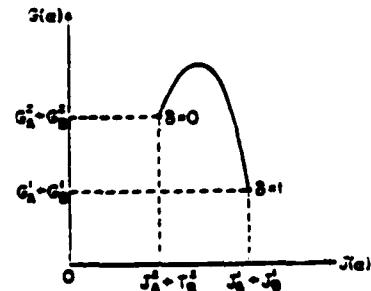


Figure 8. System Workload Performance Locus

If for all the different relative task frequencies, i.e., $0 \leq \epsilon \leq 1$, the assumption

$\delta_A = \delta_B = \delta$ is always kept, then J-G plots similar to that in Fig. 8 can be drawn for each value of ϵ . To display all these J-G plots in such a format that the performance of single-task processing and dual-task processing can be compared, G can be plotted in a polar coordinate plane with its radial coordinate being the system performance J and the angular coordinate being proportional to the task division parameter ϵ , i.e.,

$$0 \leq \frac{\epsilon}{2} \leq \frac{\pi}{2} \quad \epsilon \in [0, 1]$$

where $\epsilon = (\theta/\pi/2)$.

Therefore, a typical J-G plot of the system for all possible values of ϵ may look like the curved surface in Fig. 9 which resembles part of the surface area of a toroid with curved edges. Its edges at $\delta=0$ and $\delta=1$ are curved upward with respect to G because, for a particular decision strategy, the system activity G is a convex function of the task division parameter δ . The other two edges of the curved surface in Fig. 9 are the J-G plots for the single task processing. The projection of the surface on the J- ϵ plane will be a curved area in the shape of a quarter toroid as shown in Fig. 10.

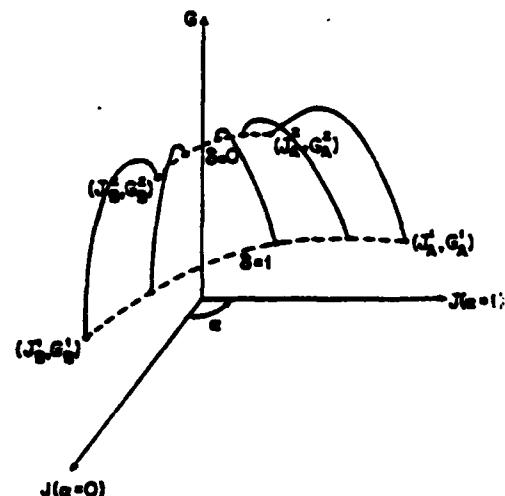


Figure 9. System Workload Performance Loci of Changing Task Division Parameter ϵ

When the system exhibits bounded rationality behavior, the plane of the activity threshold G may cut through the curved surface in Fig. 9. The surface above the cut corresponds to the region where the workload exceeds the bounded rationality constraint. The remaining surface represents the region with admissible strategies. The projection of the remaining surface on the J- ϵ plane will allow comparison of performance between single-task processing and dual-task processing. Depending on the numerical specifications of the problem, the projection of the region that results from admissible strategies may look like Fig. 11.

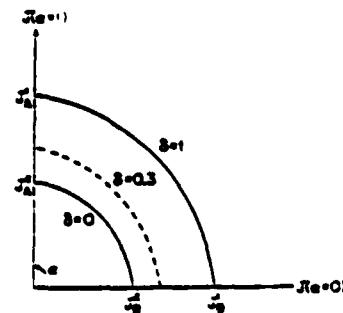


Figure 10. Projection of Fig. 9 on the J- ϵ Plane

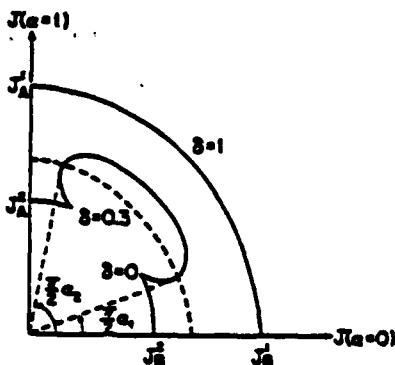


Figure 11. Projection of Locus Due to Admissible Strategies on the $J-a$ plane.

The locus in Fig. 11 is obtained by considering a plane of constant G in Fig. 9 that is above the $s=1$ boundary of the (G, J_A, J_B) surface and intersects the $s=0$ boundary. This is illustrated in Fig. 12. For $s=0.3$, a large central segment of the $G-a$ curve exceeds the threshold level G_p . Because of the convexity of the $G-a$ curves, the eliminated segment is defined by the interval (a_1, a_2) . Similarly, a segment of the $s=0$ curve, the $s=0.6$ curve, and the ones for intermediate values of s , are eliminated. This results in the shape shown in Fig. 11.

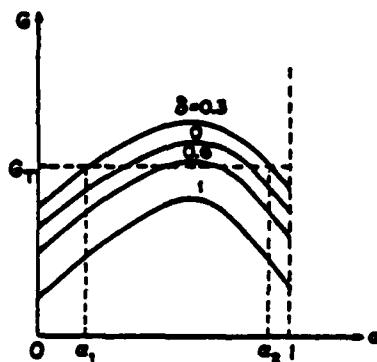


Figure 12. $G-a$ curves for various values of s

It can be observed in Fig. 11 that under the constraint of bounded rationality ($G \leq G_p$), the decisionmaker doing a single, or almost a single task, achieves a wider range of performance values, including the optimum ones. This is evidenced by the locus near the axes $a=0$ and $a=1$. When both tasks have to be carried out, the range of values of the performance is smaller; many of the better values are not achievable. Such a deficiency can be explained by the need for extra time and energy for a decisionmaker to adjust in handling a different task. Hence, in general, a decisionmaker performs better in processing a single task than processing two different tasks in sequence, even though the incoming task rate for both cases are the same. These results, based on the analytical model, are consistent with the experimental results obtained by Kelly and Greitzer (1982) and provide a plausible interpretation for the observed degradation of performance.

CONCLUSIONS

One of the uses of a preprocessor is to reduce the workload in the situation assessment stage of a decisionmaker by processing the input data.

A preprocessor can also be used to facilitate a decisionmaker in handling a dual-task. Such a preprocessor functions as a matching algorithm to yield appropriate decision strategies for processing two kinds of inputs. It has been shown that a decisionmaker carrying out a dual-task cannot perform any better than when he executes a single task. This is due to the readjustment effort required by the decisionmaker to handle the different, non-synergistic tasks. The analytical results provide an interpretation of recent experimental results.

The main focus of this paper was to present models of preprocessors and methods for their analysis. This constitutes the first step in the development of a mathematical theory and procedures for the design of decision aids. Indeed, several simple necessary conditions have been derived that decision aids must satisfy, if their effect is not to be detrimental to the decisionmaker, i.e., if they are not to cause degradation of a decisionmaker's performance.

REFERENCES

Boettcher, K. L. and A. H. Lewis (1982). Modeling the Interacting Decisionmaker with Bounded Rationality. *IEEE Trans. on Systems, Man, and Cybernetics*, Vol. SMC-12, No. 3.

Boettcher, K. L. and Lewis (1983). Modeling and Analysis of Teams of Interacting Decisionmakers with Bounded Rationality. *Automation*, Vol. 9, No. 6.

Chyan, E.-L. (1984). Information Theoretic Models of Preprocessors and Decision Aids. MS Thesis, LIDS-TR-1577, Laboratory for Information and Decision Systems, MIT.

Conant, R. C. (1976). Laws of Information Which Govern Systems. *IEEE Trans. on Systems, Man, and Cybernetics*, Vol. SMC-6, No. 4.

Hall, S. A. (1982). Information Theoretic Models of Storage and Memory. SM Thesis, LIDS-TR-1232, Laboratory for Information and Decision Systems, MIT, Cambridge, MA.

Kelley, R. T., and F. L. Greitzer (1982). Effects of Task Load on Decision Performance in Simulated Command and Control Operations. NPLDC-TR-82-21, Navy Personnel Research and Development Center, San Diego, CA.

Levis, A. H., and K. L. Boettcher (1983). Decisionmaking Organizations with Acyclical Information Structures. *IEEE Trans. on Systems, Man, and Cybernetics*, Vol. SMC-13, No. 3.

END

FILMED

11-85

DTIC